Calculation of Blood Pulse Transit Time from PPG

a thesis submitted in partial fulfillment of the requirements for a degree of

Bachelor of Technology

in

Biomedical Engineering

by

BHAVIRISETTY RAVI TEJA

Roll No. : 108BM011

Department of Biotechnology and Medical Engineering

National Institute of Technology, Rourkela

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Under the guidance of

Dr. Subhankar Paul

Department of Biotechnology and Medical Engineering

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Rourkela

CERTIFICATE

This is to certify that the thesis entitled ***"Calculation of Blood Pulse Transit Time from PPG"*** submitted by Mr. Bhavirisetty Ravi Teja (108BM011) in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Biomedical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my guidance.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma.

Dr. Subhankar Paul Date:

Associate Professor

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Rourkela – 769 008

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Submitted by:

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ABSTRACT

Photo Plethysmograph (PPG) is an instrument that assists in monitoring the volumetric changes in our body. It uses LEDs and their corresponding sensors as pairs in retrieving information in the form of electrical signals (low in amplitude). The signals are amplified and processed using various filters to give the desired output. The blood pulse wave in the form of a voltage signal is derived at two points, one FINGER and the other WRIST. The time difference between two corresponding peaks gives us the PULSE TRANSIT TIME (PTT). This PTT has various clinical applications in assessing few vital parameters in an easy and non-invasive way.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Blood Pressure (BP) is the force of the blood contained by the arteries. It is created primarily by the contraction of the cardiac muscles. It is measured or recorded by two numbers. The first, *Systolic Pressure,* is measured when the heart contracts which is highest. The second, *Diastolic Pressure*, is measured when the heart relaxes or expands and is lowest. BP is a significant physiological parameter in monitoring a patient's health condition. It is an indication of various cardiovascular conditions, which makes it an important medical research or clinical parameter.

Blood Pressure can be estimated either by invasive or non-invasive methods. Continuous monitoring is seen in invasive techniques but it is tough to set up and infection prone too. The non-invasive techniques are the *Korotkoff* and *Oscillometry* methods [1]. Although these non-invasive techniques give us accurate readings, they are confined to one point of time only. Moreover, the subjects experience discomfort while the readings are taken.

The BP, cubage and flexibility of arteries are directly related to the Pulse Wave Velocity (PWV) [2]. This PWV gives us an excellent chance to monitor the BP continuously, in a non-invasive manner. PWV is not an easy parameter to be measured at a clinical level. So, Pulse Transit Time (PTT) is often a substitute for the PWV. The PTT and BP are inversely related and the relation stands steady over a certain period of time for an individual [3]. PTT decreases with an increase in BP.

1.2 MOTIVATION

Healthcare is an important issue to be addressed in a country like India. It is a growing concern among people to have a check on their health status themselves. This issue has to be addressed with many continuous health monitoring devices which have to be economical, portable, reliable and easy to operate even by a normal individual. This gives a chance to improve the healthcare facilities in more rural places where advanced equipment is not an option.

1.3 PRESENT DAY SCENARIO

Many numbers of mobile monitoring devices are available commercially these days, some of them being the *UT100 Portable Pulse Oximeter* and *PC-60C Portable Pulse Oximeter*.

Continuous monitoring of the vital parameters without disturbing the daily chores is an important requirement for the patients. They also need them to be practical as well as easy to handle.

Such systems also help the medical professionals in making their work easy and give them more time to concentrate on the patient's health condition. There is no necessity for any supervisors to be present with patients at all times to monitor and carry around the equipment.

Fig 1.1: Portable Pulse Oximeter UT100 (*Image courtesy: http://cutech.en.made-in-china.comproductfesEzRhvXqWHChina-Portable-Pulse-Oximeter-UT100-.html*)

Fig 1.2: Portable Pulse Oximeter PC60C (*Image courtesy: http://www.24-7pressrelease.com/press-release/pulse-oximeters-directcom-unveils-revolutionary-new-pc60c-portable-pulse-oximeter-139366.php*)

A patient's current condition can be fully estimated at a particular time using the following parameters:

- PULSE RATE (or Hear Rate)
- BLOOD PRESSURE
- RESPIRATORY RATE
- OXYGEN SATURATION LEVELS (it is seldom used)

They are often regarded as the *Vital Physiological Parameters* [4]. All the above parameters can be non-invasively estimated by a reflectance PPG sensor. Blood Pressure is derived from the PTT. PTT is in turn derived from the combination of ECG and PPG [5, 6].

1.4 OBJECTIVES

The foremost objective of the task is to instrument two reflective PPG sensors with the suitable specifications for a wearable monitoring system. The design norms for wearable monitoring of the PPG sensor comprise of the LED features, placement of the sensor, covering of the sensor and hardware development intended for two reflectance based PPG sensors. In view of the above requirements the objective of the project can be stated as below:

- We have to develop reflectance PPG sensors (two) in order to obtain the signals without losing any diagnostic values.
- Derive the PTT between the signals from two PPG sensors using any suitable software.

CHAPTER 2
BACKGROUND THEORY

2.1 MECHANISM OF THE PULSATILE FLOW OF BLOOD:

This pulsatile behavior of heart can be attributed to the collective activities of Atrioventricular node (AVN), Sino-Atrial node (SAN), Bundle of His, Atrioventricular valves, Purkinje fibers and Semi-lunar valves. SAN, a group of cells in the right atrium, next to the entry of the vena-cava initiate the heart activity which act as the biological or natural pace maker for the heart. Impulses are generated at the normal rate (i.e., 72 beats per minute at rest for a normal subject). The impulse wave moves through the right and left atria. This impulse conducts through the atrial valve to AVN; situated between the two atria. The action potential is carried to the ventricles by The Bundle of His. The delay in transmission of action potential ensures the proper contraction of heart chambers, the atria and the ventricles. The contraction of ventricles squeezes the blood out of ventricles, with a force, into the arterial system. Therefore, the arterial pulse is the fluctuation caused due to heart contraction which occurs at an equal frequency as the heart rate [7].

2.2 PHOTOPLETHYSMOGRAPHY

The tissues in the human body are generally considered to be opaque, while transmission of light is seen at the skin or soft tissue levels. Wavelength of red light is comparable with color of blood; this near red is more perceptible than other wavelengths or colors. By means of this property of tissues, *Photoplethysmograph* acquires the information associated with pulsation by collecting the transmitted signals [8].

When light is incident from the source, a part of the incident light is reflected, a part is absorbed and the remaining is transmitted. The absorption rates of light differ with the locations. As shown in Fig: 2.1, only blood vessels show curved shapes. The shape changes are under the influence of the pulsation of blood.

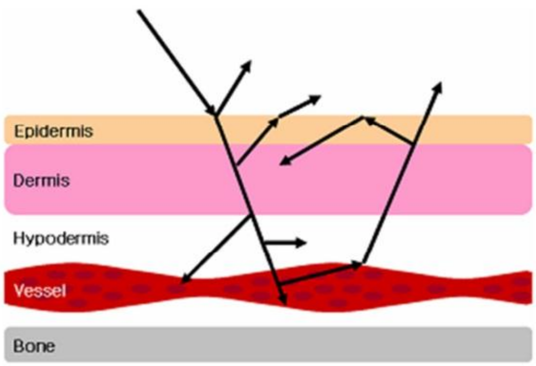


Fig 2.1: Optical property of human body

The below figure (Fig: 2.2) shows a symbolic detected signal. The signal is primarily categorized into two components. One being ‘DC’ or static signals obtained from static elements of our body tissue for instance epidermis, dermis, hypodermis and bone which are hardly changeable. The second category contains the ‘AC’ or dynamic signals which are all almost from blood vessels. As stated earlier, the contour of blood vessel alters due to pulsation from the heart, which is the main working principle of Photoplethysmograph.

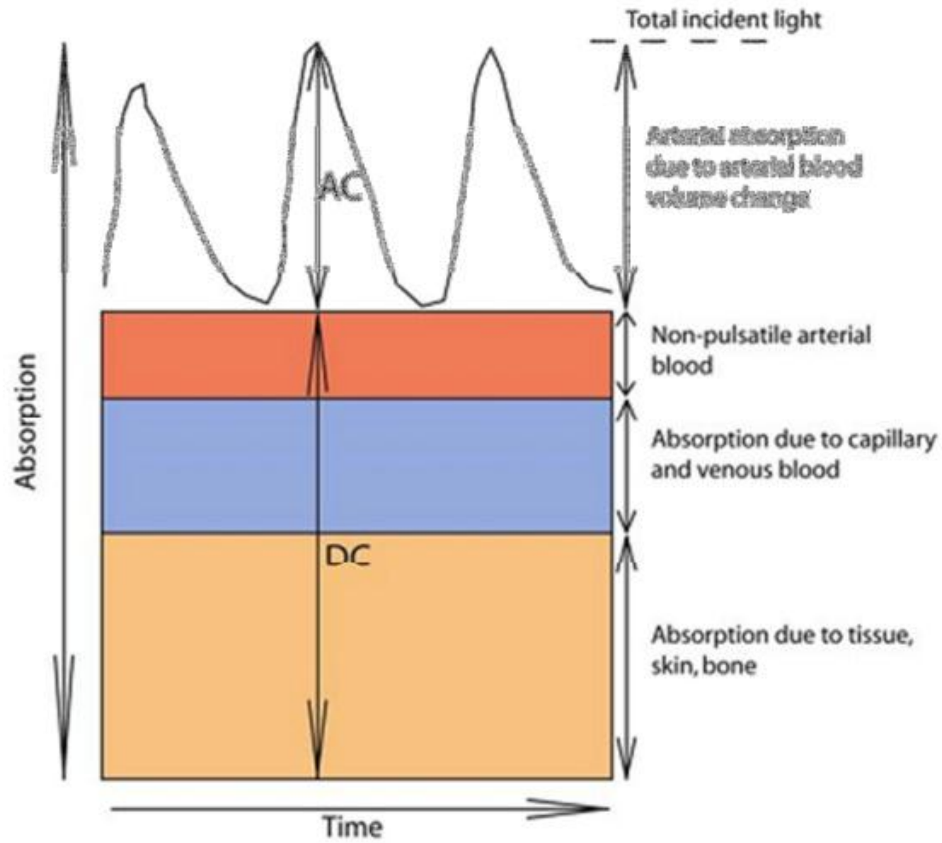


Fig.2.2 PPG signal with AC and DC components

2.3 TYPES OF PPG

There are two different methods of measuring PPG waveforms:

- Reflectance PPG
- Transmission PPG

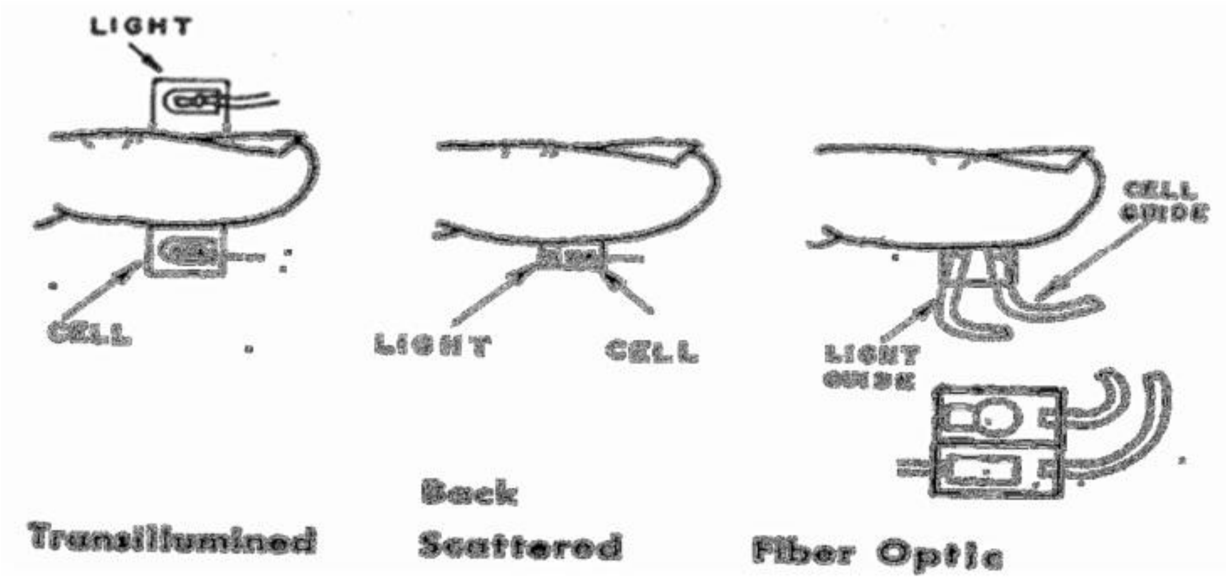


Fig 2.3: Illustration of finger PPG, *Courtesy: Michael Maguire and Tomas Ward; "The Photoplethysmograph as an instrument for physiological measurement."*

The above figure (Fig 2.3) demonstrates the two types of PPG measurement in brief. The following figure (Fig 2.4) displays the transmitted type probe. Here the detector is positioned opposite to the emitter's side. Transmitted signal has much strength than reflected signal when taken over a smaller area. So, the benefit of this kind is we get a clear signal. But the limited area is also a disadvantage to transmit the light. Fingers, Ear Lobes and Toes are usually the locations to take the PPG readings.

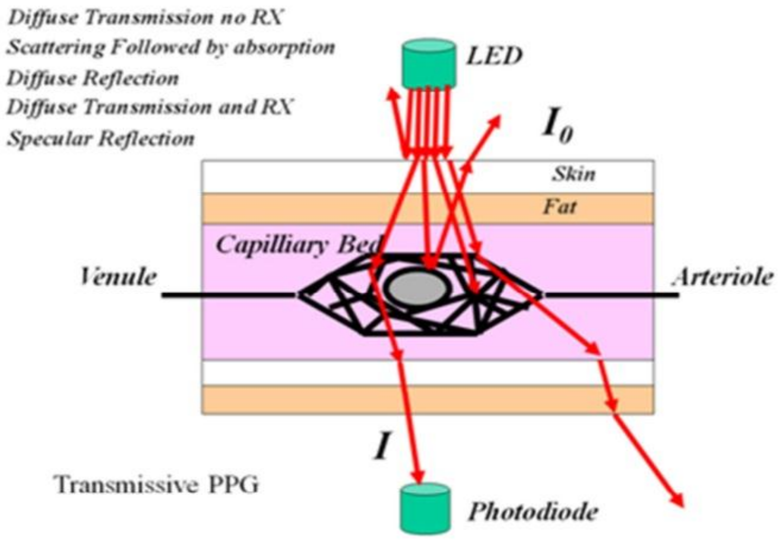


Fig 2.4: Transmitted type PPG's probe, *Courtesy: Michael Maguire and Tomas Ward; "The Photoplethysmograph as an instrument for physiological measurement."*

The figure (Fig: 2.5) portrays reflection type probes. These types detect the reflected light at the tissue levels. In the previous figure (Fig. 2-3 (b)), the reflection pathway between emitter and the detector is a complex one. The amount of reflected light is very small in comparison to the transmitted type. Hence, weak signals are detected on the PPG. The light here cannot be transmitted. So, theoretically we now do not have a limited area which becomes our main advantage.

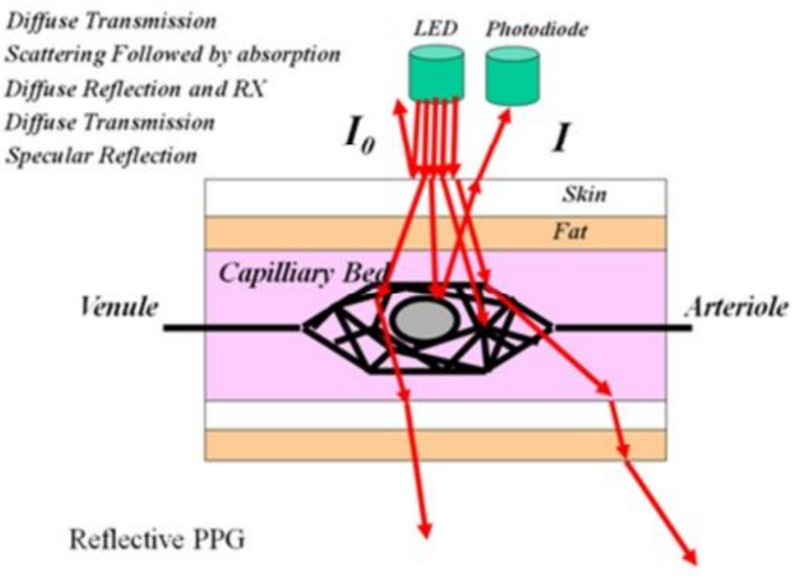


Fig 2.5: Reflection type PPG is adapted from reference. *Courtesy: Michael Maguire and Tomas Ward; "The Photoplethysmograph as an instrument for physiological measurement."*

The following figure (Fig: 2.6) embodies the proper applicable regions in the human body to retrieve the PPG signals. Fingertip is the most common area, Ear lobe is the thinnest region for this application, and for infants the instep of the foot is usually a preferred location they have very small areas at the Ears and Fingers. Reflected type probes are used by researchers at the finger in a ring casing [9], at the forehead as a helmet or a hair band [10] and the esophagus for patient operative care [11].

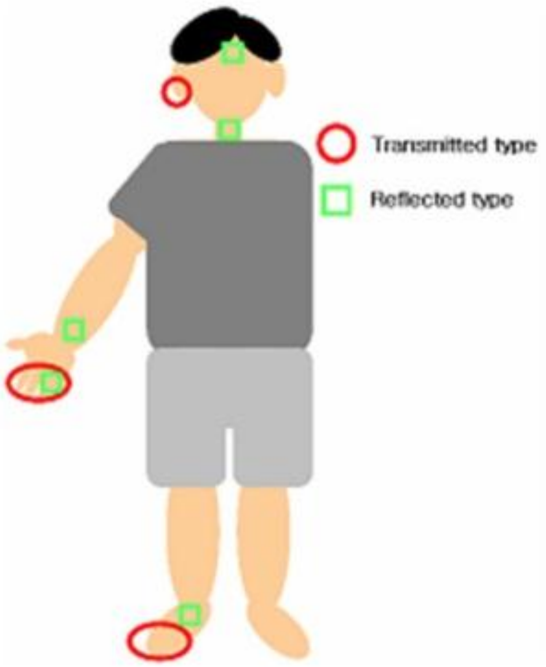


Fig 2.6: Area of detected signal with each type of Photo-plethysmograph

2.4 CLINICAL APPLICATIONS OF PPG

PPG is applied at various clinical settings like: Clinical Physiological Parameter Monitoring (Heart Rate, Blood Pressure, Blood Oxygen Saturation, Respiration and Cardiac Output), Vascular Assessment (Arterial Compliance, Arterial Disease and Ageing, Endothelial Function, Vaso-Spastic Conditions, Venous Assessment) and Autonomic Function (Thermoregulation and Vasomotor Function, Blood Pressure and Heart Rate Variability, Neurology, Orthostatic Intolerance and further Cardiovascular Variability Assessments).

2.4.1 MONITORING HEART RATE AND CARDIAC CYCLE

The skin is richly perfused. So, it is comparatively very easy to detect the pulsatile constituent of the cardiac cycle. The DC constituent of the signal is attributed to the bulk absorption by the skin tissue, whereas the AC constituent is directly attributed to the variation in blood volume through the skin that is caused by the pressure pulse of the cardiac cycle.

2.4.2 MONITOR RESPIRATION

The total net effect of respiration helps as a pump for the cardiovascular system. As the depth and frequency of respiration increase, the venous return increases. This leads to an increase in the cardiac output.

2.4.3 MONITOR DEPTH OF ANESTHESIA

An insufficient anesthetization to a patient immediately generates a sympathetic nervous system response to any incision which in turn generates a sudden peak in the PPG waveform.

2.4.4 MONITOR HYPO- AND HYPER-VOLEMIA

One may detect the blood loss from the Photo-Plethysmograph, from a Pulse Oximeter or an arterial catheter. A cardiac preload reduction during exhalation while the heart compresses leads to decrease in the cardiac pulse amplitude of the PPG waveform.

2.5 PULSE TRANSIT TIME

Pulse Transit Time (PTT) is the time taken by a pulse wave to propagate from heart to a specified point on the body where the reading is taken, normally the finger or ear lobe. PTT is non-invasive and a simple measurement. PTT is defined as the time duration from a reference point of time, for the pulse pressure wave to travel to any specified point on the periphery (fig: 2.7 displays the pulse transit time). Blood Pressure changes, Heart Rate and the compliance of the arterial walls, and so on influence the PTT. [12]

From the ECG and Peripheral Pulse Wave, at every heart beat PTT is calculated. The Peripheral Pulse Wave can be measured by a SpO_2 probe at the finger or toe. There is no requirement of additional sensors or modules.

This model estimates the pressure difference between the two sites, the heart and the fingertip, by the pulse wave velocity. A pulse wave travels from the heart to the fingertip, along the artery and its velocity can be calculated from the distance travelled divided by the PTT [13] [14].

The PTT between two points of measuring site, can be measured in seven methods : (1) the first derivative method, (2) the second derivative, (3) the minimum, (4) the intersecting a line tangent, (5) the maximum, (6) the middle point between minimum and maximum, (7) the intersecting two line tangents [15].

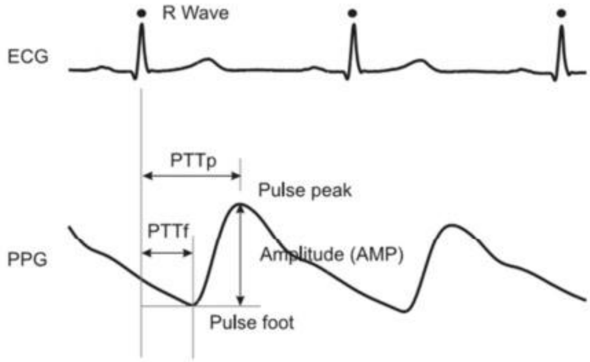


Fig 2.7: Pulse Wave Transit Time between ECG and PPG. *Courtesy: John Allen; 'Photoplethysmography and its application in clinical physiological measurement.'*

2.6 LIMITATIONS OF THE PTT USING ECG AND PPG

The customary method to calculate PTT is to use the QRS complex from the ECG as a time reference. This may not be the optimum reference to use as found out from the previous studies. The QRS complex is an electrically signal, a depolarization event which represents the point of expulsion of blood from the left ventricle. It is believed that there may be disparities regarding the iso-volumetric contraction period of the left ventricle, making it an unsuitable one as a time reference [14].

It is compulsory to synchronize the ECG and PPG correctly. There are some PPG sensor units that have built-in filters which are quite dissimilar to the ECG filters. These filters often generate an artificial phase-lag between the ECG and PPG. This alters the PTT length giving us a wrong reading [14].

The R peak signifies the electric excitation of the heart contraction (ventricular contraction); a small delay is observed before the initiation of the mechanical contraction. The delay is called the Pre-Ejection Period (PEP). It is very difficult to measure the PEP (the PTT detected includes the PEP) which has a negligible value as compared to the actual PTT. There is a notion that for subjects possessing a low heart rate, PEP may have a significant role [14].

The PTT (derived from the ECG peak) seems to be a cumbersome approach considering all the above specified in wearable monitoring implementation. Therefore, we propose a new approach to estimate PTT by considering two different locations, one being the wrist and the other being the finger, which lie on a same arterial path. Here the co-location of both sensors by reducing the distance will help in overcoming the hydrostatic pressure consideration as compared with the later technique. This technique is employed for the design and estimation of PTT by developing the wrist based PPG sensor and finger PPG sensor.

2.7 PULSE WAVE VELOCITY MEASUREMENTS USING PTT

Pulse Wave Velocity (PWV) is related to BP, the cubage and flexibility of the arteries [2]. Thus PWV, a potential tool, is useful and a convenient parameter in continuous monitoring of Blood Pressure. Yet it is tough to measure PWV at clinical level. So, it is replaced by Pulse Transit Time (PTT).

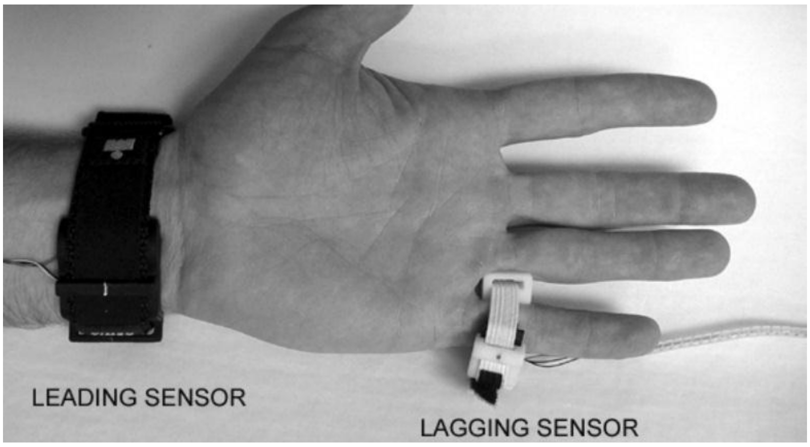


Fig: 2.8: PPG sensor arrangement used to measure peripheral pulse transit time. *Courtesy: Devin B. McCombie, et al; "Adaptive blood pressure estimation from wearable PPG sensors using peripheral artery pulse wave velocity measurements and multi-channel blind identification of local arterial dynamics"*

Peripheral PWV measurement is performed using two PPG sensors as demonstrated in the above figure (Fig. 2.8). The photodiode of the leading sensor is placed directly above the ulnar artery near the wrist joint. The photodiode of the lagging sensor is placed above the digital artery of the little finger. The Pulse Transit Distance (Δx) between the two sensors is measured as the distance between the upstream edges of the two photodiodes. The Pulse

Transit Time (Δt) of the pressure pulse is measured as the difference in time between the time of the onset of the pulse wave measured at the lagging sensor and the time of the onset of the pulse wave at the leading sensor.

In this project we defined the Pulse Transit Time as, *the time interval between the peak of Wrist PPG and Peak of finger PPG respectively*.

CHAPTER 3

METHODOLOGY

3.1 BLOCK DIAGRAM OF METHODOLOGY

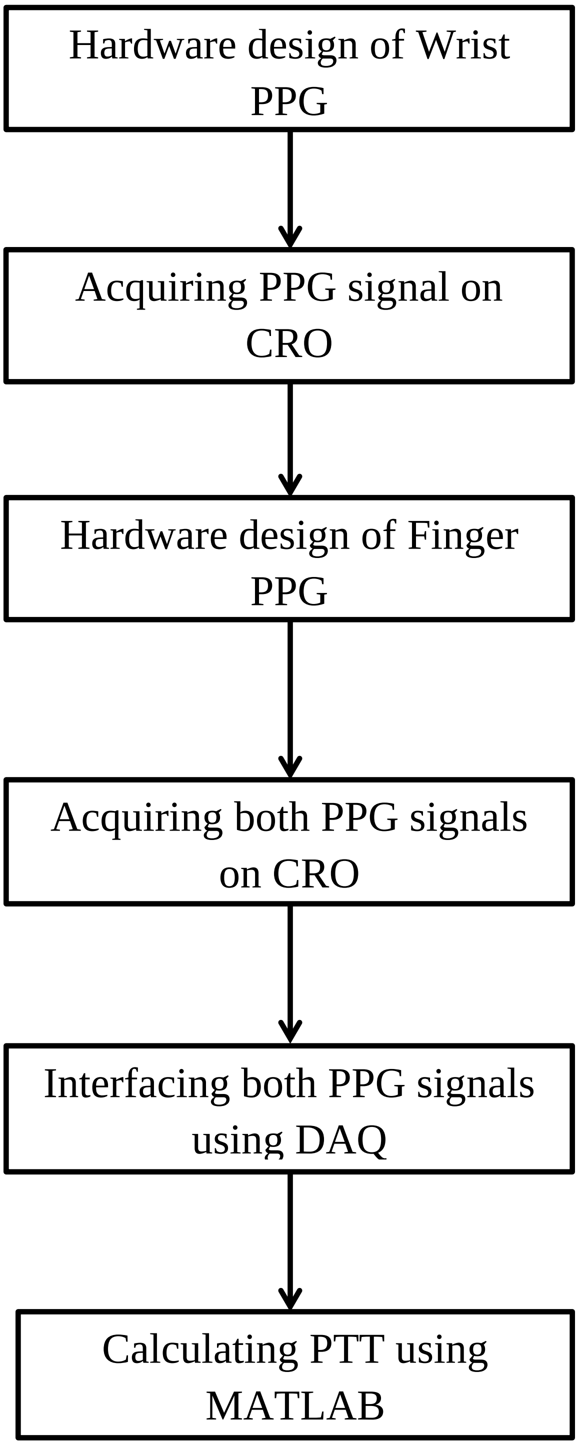


Fig 3.1 Block Diagram of Methodology

Two reflectance PPG circuits are designed to obtain the signals, one from the wrist and the other from the finger such that no diagnostic value of the PPG is lost.

3.2 HARDWARE DESIGN

The figure below demonstrates the block diagram of the system used to acquire the PPG data through electrical signals from the PPG sensor. The analog section receives input from the sensor placed on the skin in the form of current (I). In the first stage current (I) is converted to voltage (V); this is because output from the optical sensor is current which has to be converted to voltage for further processing. In the second stage, the signal is fed to a precision amplifier with a gain of 1000. In further stages the signal is filtered using a second order HIGHPASS Butterworth filter with an upper cut off frequency of 0.5Hz and then a second order LOWPASS Butterworth filter with a lower cut off frequency of 20Hz. The band limited signal is then fed finally through a Notch filter to remove 50Hz power line noise.

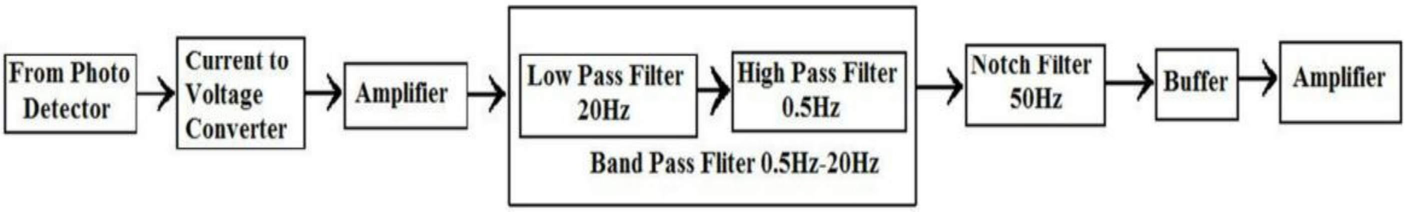


Fig 3.2 Block Diagram for PPG detector circuit

3.3 BLOCK DIAGRAM DESCRIPTION

3.3.1 LIGHT SOURCE

The light source used here is a infra-red LED of peak wavelength 940nm at 20mA current.

3.3.2 PHOTO DETECTOR

Photo diode and photo transistor are used as photo detectors in PPG. A photo detector produces current proportional to light intensity they are exposed to. Photodiodes have a quicker response time than Phototransistors. The response ranges from n-Sec to µ-Sec respectively.

3.3.3 CURRENT TO VOLTAGE CONVERTER

There is a need to convert the output of photodiode which is in milliamps to voltage for further signal-conditioning. Here we make use of the concept that if a current I flows through a resistor R, the latter impedes the current. As a result, a proportional voltage drop, V=IR appears across the resistor. It is easier to condition a voltage signal than a current signal [16].

3.3.4 AMPLIFIER

An amplifier is a device that increases the amplitude of a signal. A non-inverting amplifier changes the magnitude of the signal and does not change the phase of the signal The PPG output has very low amplitude, hence, it is amplified to a desired level with a gain [16].

3.3.5 BAND-PASS FILTER

The high pass and low pass sections work together as a Second order Butterworth Band pass filter. A band pass filter is used as a frequency selector. It allows one particular band of frequencies to pass. Thus the pass band is between the two cut off frequencies f_L and f_H i.e. between 0.5Hz and 20Hz (in this case). Any frequency outside this band gets attenuated. The pass band which is between f_H and f_L is called bandwidth of the filter denoted as BW [16].

$$\mathbf{BW = f_H - f_L}$$

- **LOW-PASS FILTER**

  A low-pass filter passes low-frequency signals while attenuating (reducing the amplitude of) signals with frequencies higher than the cut-off frequency. The actual amount of attenuation for each frequency varies from filter to filter. It is sometimes called a high-cut filter. The cut off here is set to 20Hz.
- **HIGH-PASS FILTER**

  A high-pass filter, or HPF, is a Linear Time Invariant Filter that passes high frequencies but attenuates frequencies lower than the filter's cut off frequency. The actual amount of attenuation for each frequency is a design parameter of the filter. It is sometimes called a low-cut filter or bass-cut filter. The cut off here is set to 0.05Hz.

3.3.6 NOTCH FILTER

The twin T notch provides a large degree of rejection at a particular desired frequency. The notch filter is useful in rejecting unwanted signals that have a particular frequency. One of the applications is to zero out unwanted mains noise at 50 or 60 Hz that may be entering a circuit. Theoretically, at the notch frequency the level of attenuation provided by the twin T notch filter is infinite. Similar to other RC circuits, the RC twin T notch filter circuit also has what may be termed as a soft cut-off. Practically, the response of the notch falls away slowly and affects a wide band of frequencies on either side of the cut-off frequency. The cut-off for this circuit is 50Hz power interference which is considered to be a noise in the PPG signal [16].

3.3.7 BUFFER

A voltage follower or buffer amplifier (sometimes simply called a buffer) is one that provides electrical impedance transformation from one circuit to another. Buffers are used in Impedance matching, the benefit of which is to maximize energy transfer between circuits or systems. It provides unity gain connects the notch filter to the output [16].

3.4 GENERAL COMPONENTS USED

- Infra-Red LED’s (QEE113)
- Photo transistor (QSE113)
- Operational Amplifiers (OP07CP)
- Passive Components
- 7805 Voltage Regulator

3.4.1 PHOTO TRANSMITTER

IR LED QEE113 is a plastic IR emitting diode manufactured by Fairchild Semiconductor Corporation.

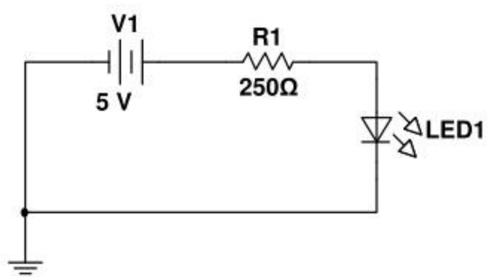


Fig 3.3 LED circuit diagram

3.4.2 CURRENT TO VOLTAGE CONVERTER

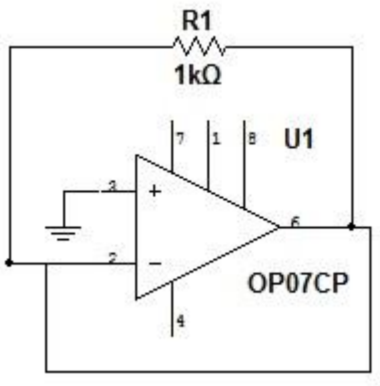


Fig 3.4 I-V Converter

3.4.3 VOLTAGE AMPLIFIER

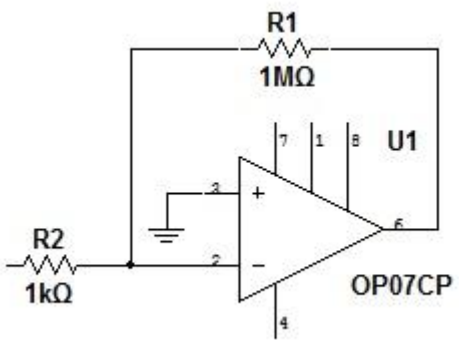


Fig 3.5 Inverting Voltage Amplifier

The gain here is 1000.

3.4.4 BANDPASS FILTER

SECOND ORDER BUTTERWORTH LOWPASS FILTER

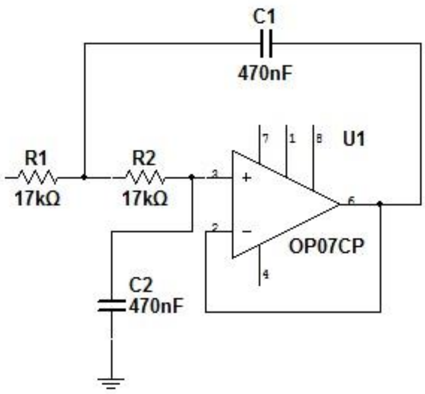


Fig 3.6 Second order low-pass Butterworth Filter

SECOND ORDER BUTTERWORTH HIGHPASS FILTER

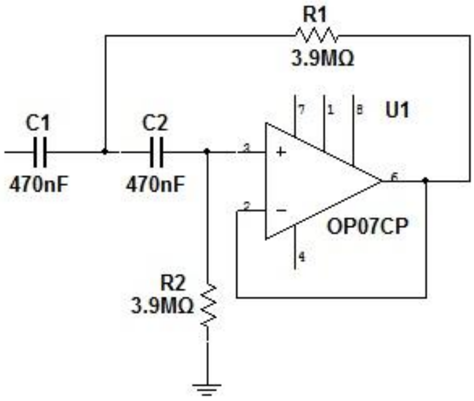


Fig 3.7 Second order high-pass Butterworth Filter

The band-pass filter has a cut-off frequency of 0.1Hz to 20Hz.

3.4.5 NOTCH FILTER

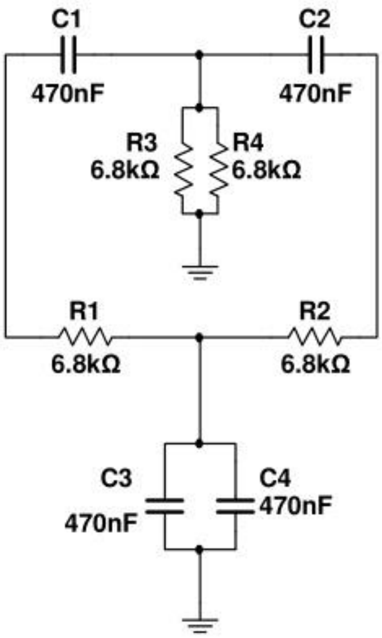


Fig 3.8 Twin T Notch Filter

The Twin T Notch filter nullifies the 50Hz noise from the main power supply line.

3.5 TOTAL PPG DETECTOR CIRCUIT

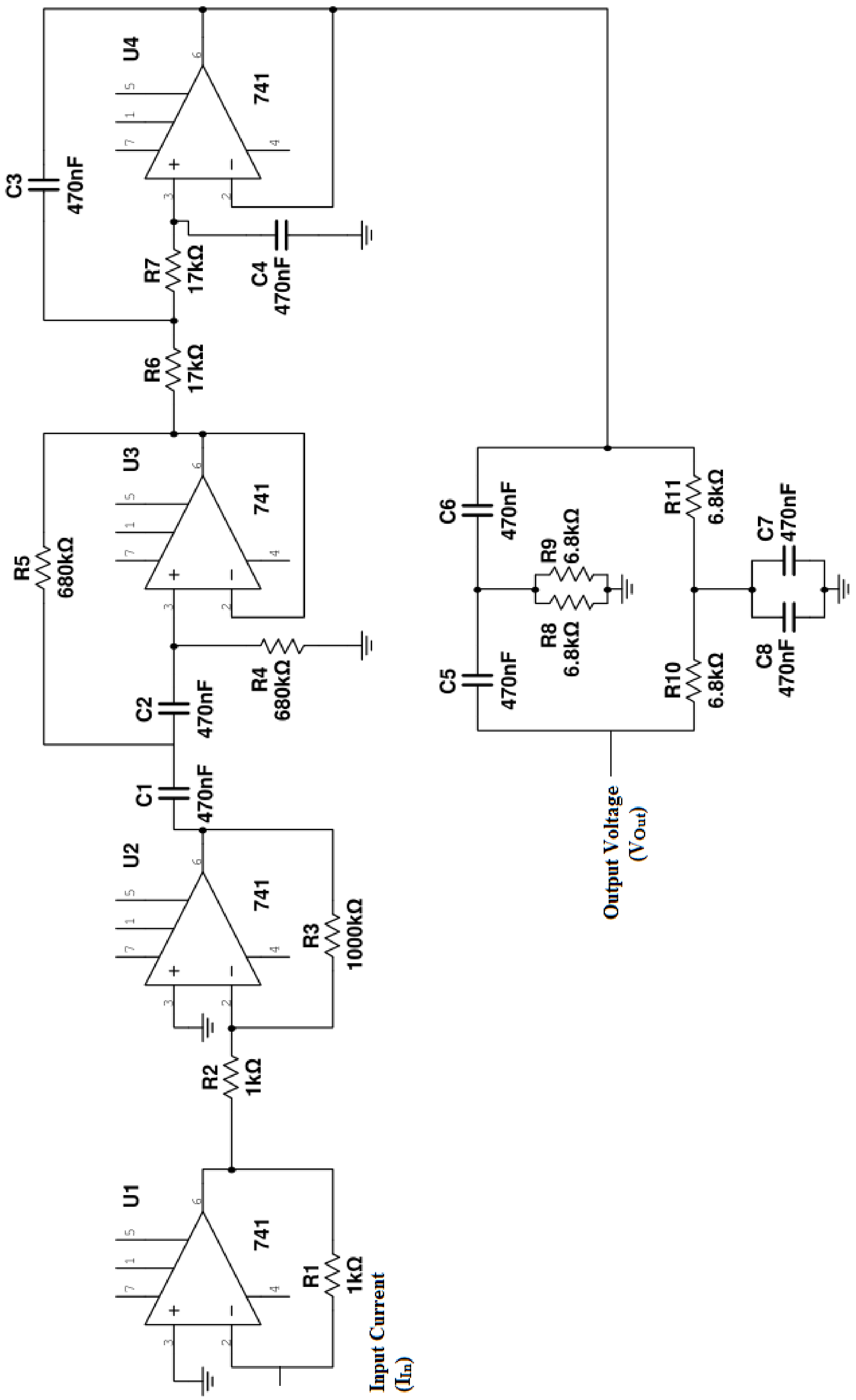


Fig 3.9 Total PPG detector Circuit designed using *NI Multisim 11.0*

3.6 DAQ INTERFACE USED

The DAQ used here is the ADVANTECH USB-4074 to acquire the PPG signals in the digital form.

3.7 ALGORITHM

Step1: Start

Step2: Read the PPG1 data

Step3: Plot PPG1 Signal

Step4: Detect positive peaks of the data by comparing 3 successive samples when the second data is higher with respect to first and third data or first and second data are equal and higher than the third data.

Step5: Copy the detected samples to peak array else check successive samples

Step6: Find the maximum peak value of peak array and set 70% of it as threshold value

Step7: If array value is less then threshold then load 0 in that respective sample

Step8: If peak value is greater than 0 then suppress the next successive 20 array values to 0

Step9: Store the peak value in an array

Step10: Store the time value with respect to peak in an array

Step11: Read PPG2 data

Step12: Plot PPG2 signal

Step13: Repeat from step 4 to step10 for the PPG2 signal

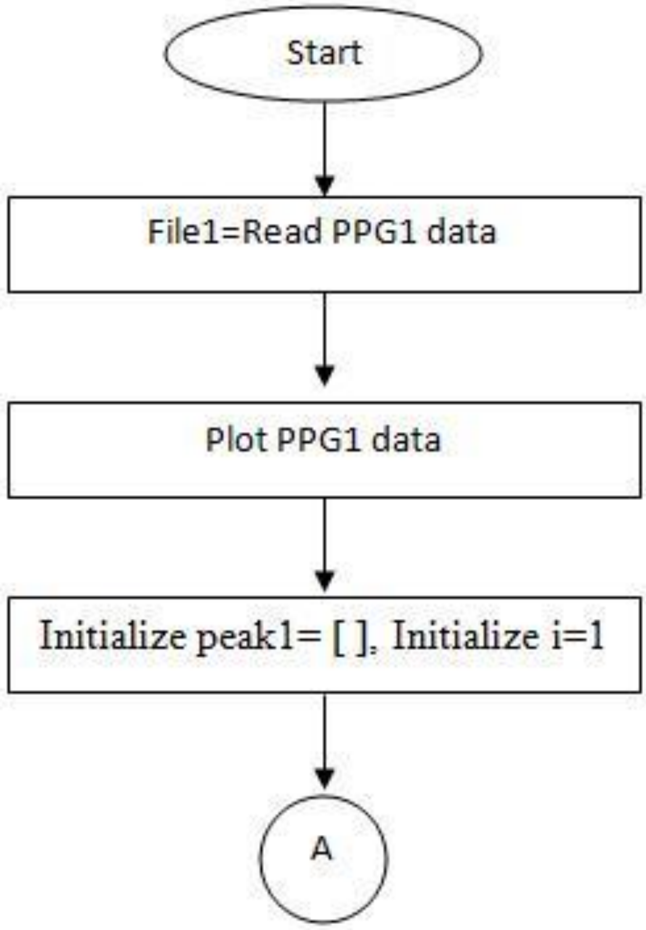
Step14: Find the difference between the time samples of PPG1 and PPG2 respectively and store the difference in an array

Step15: Find average of 8 successive time difference value and display

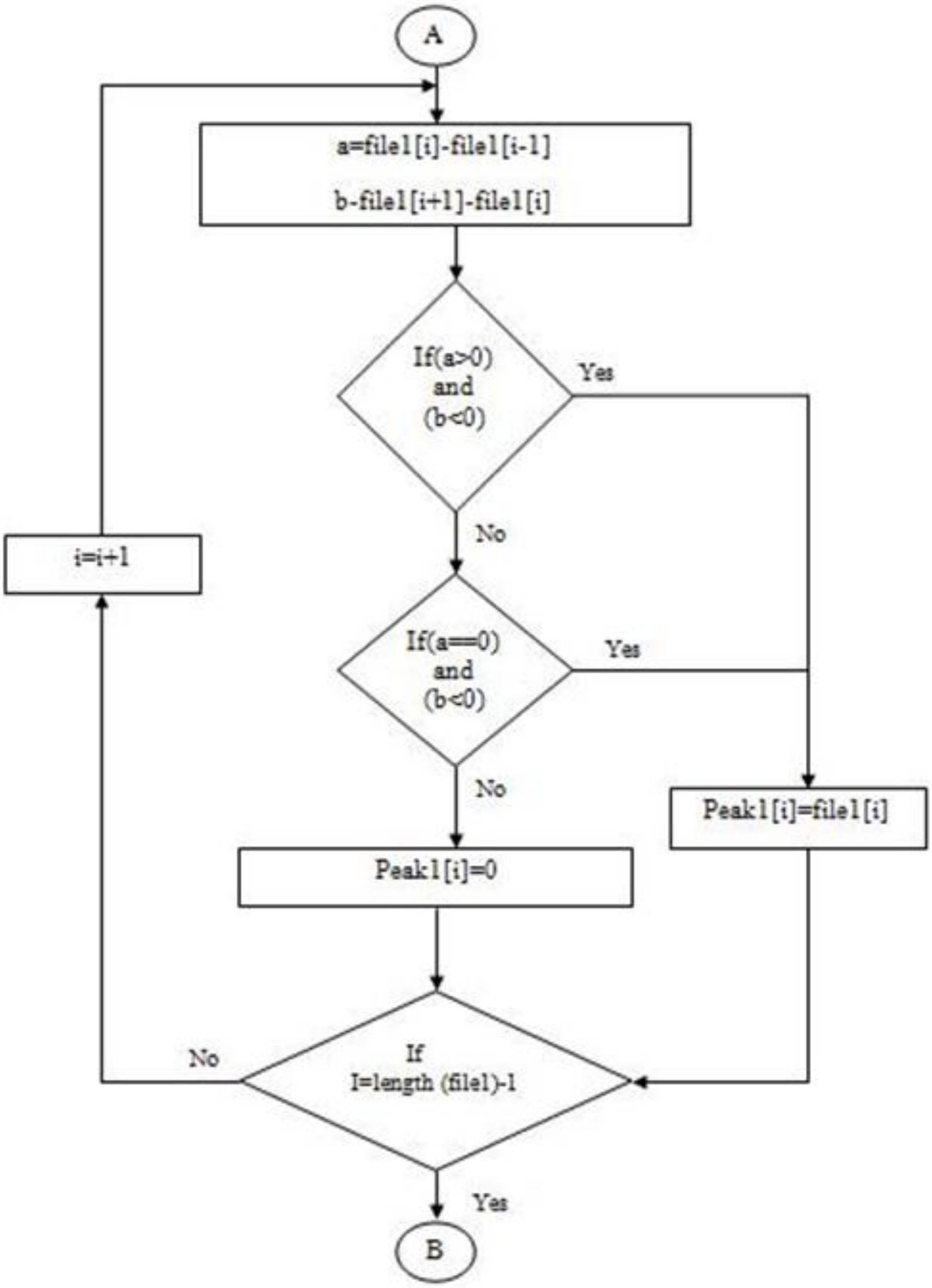
Step16: Stop

3.8 FLOWCHART

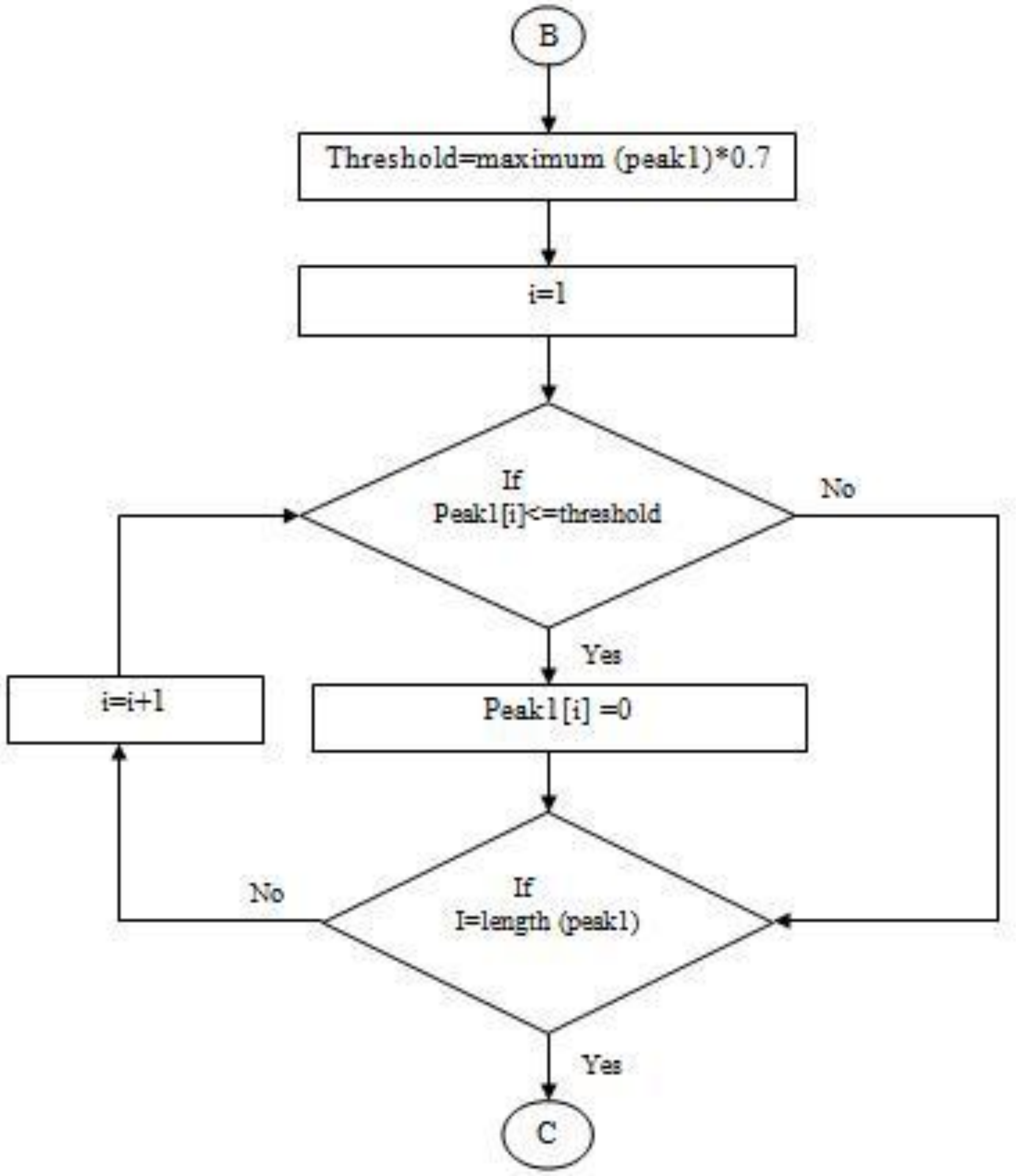
READING WRIST PPG DATA



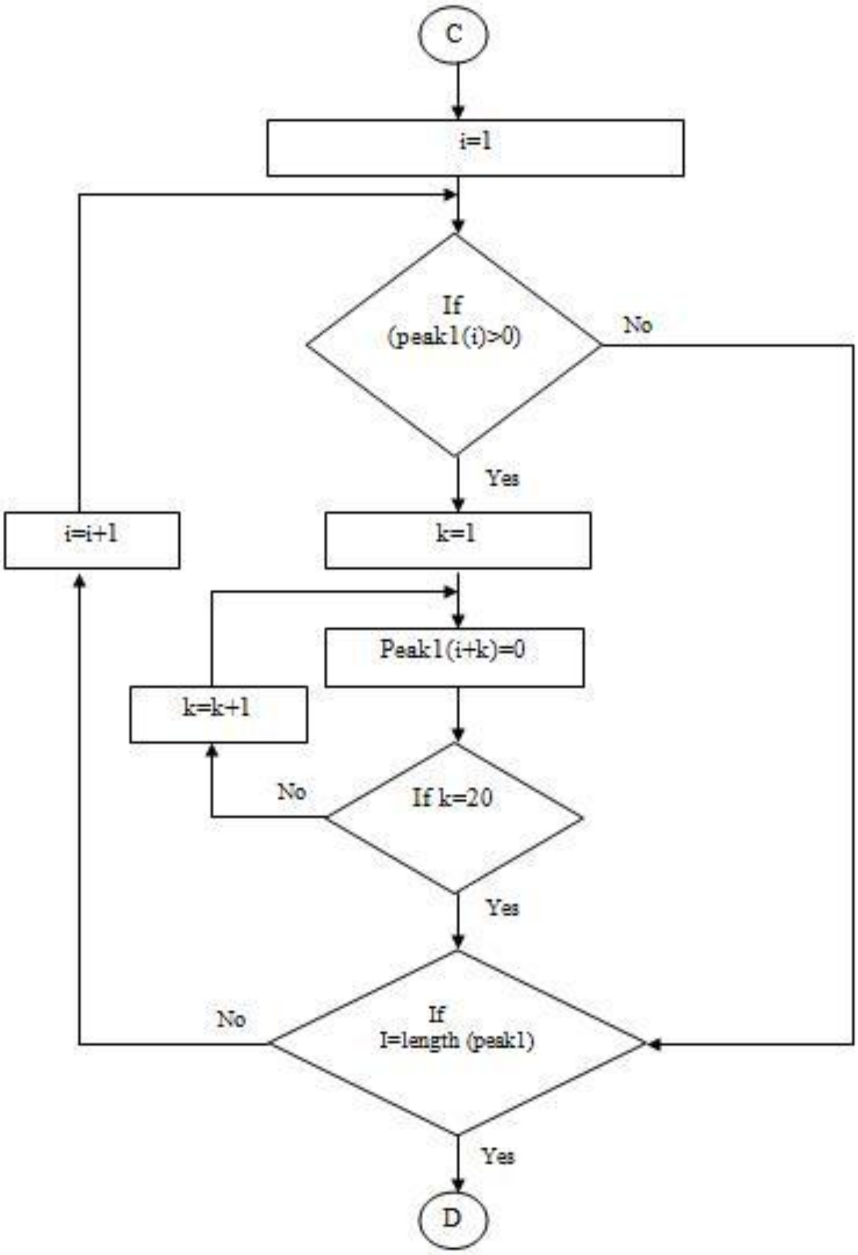
DETECTING PEAKS OFF WRIST PPG



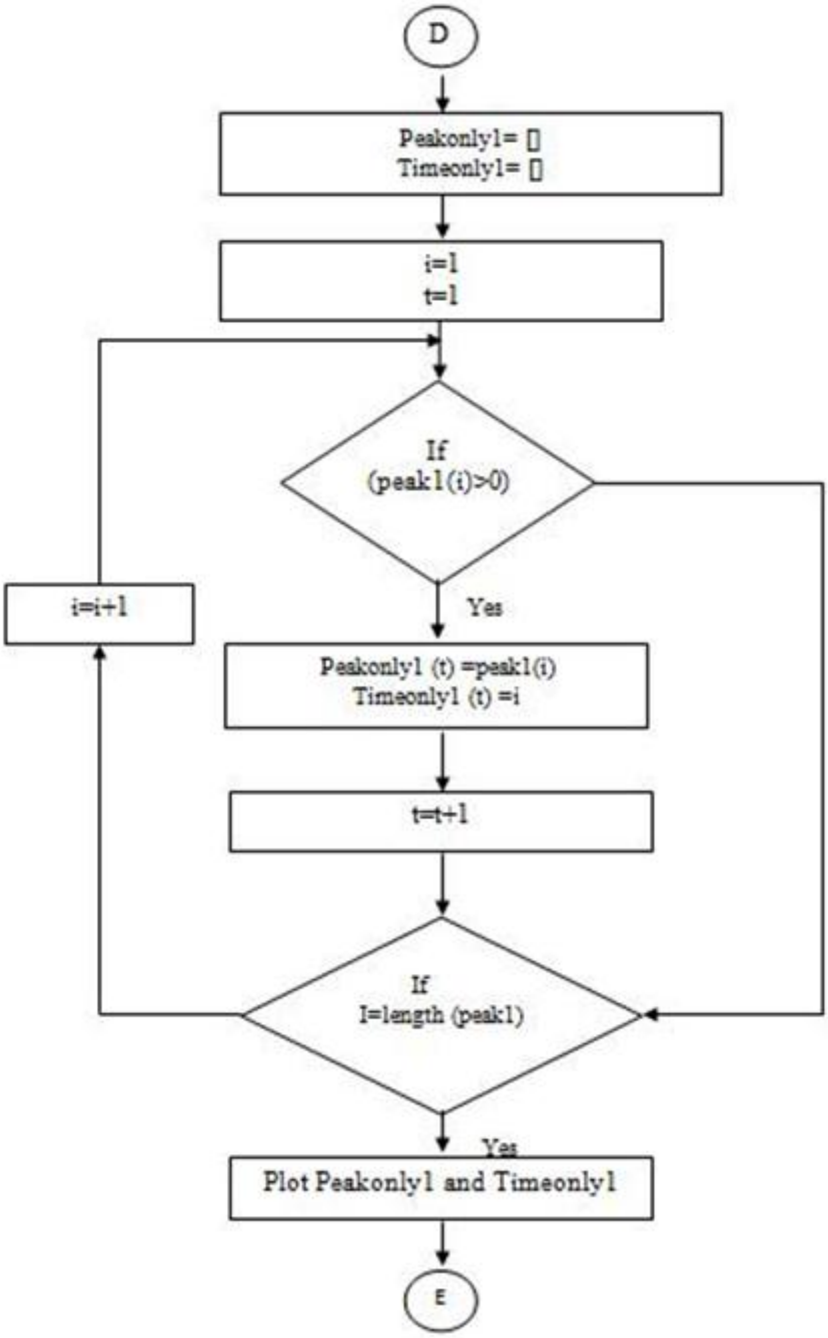
THRESHOLDING SIGNAL OF WRIST PPG



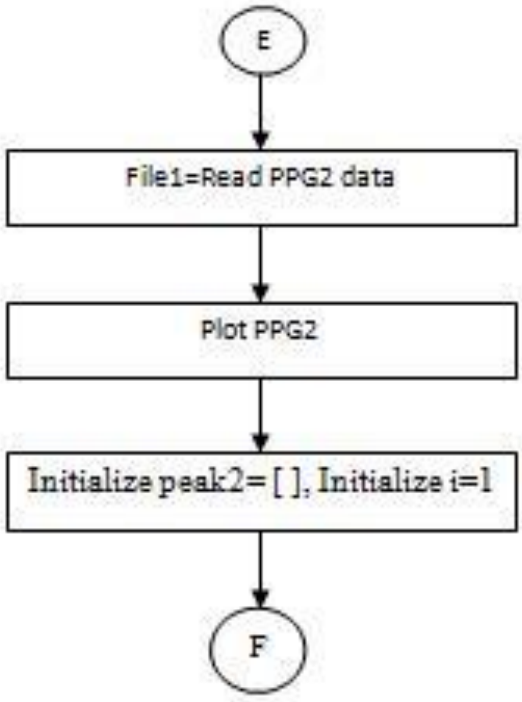
SUPPRESSING UNWANTED PEAKS



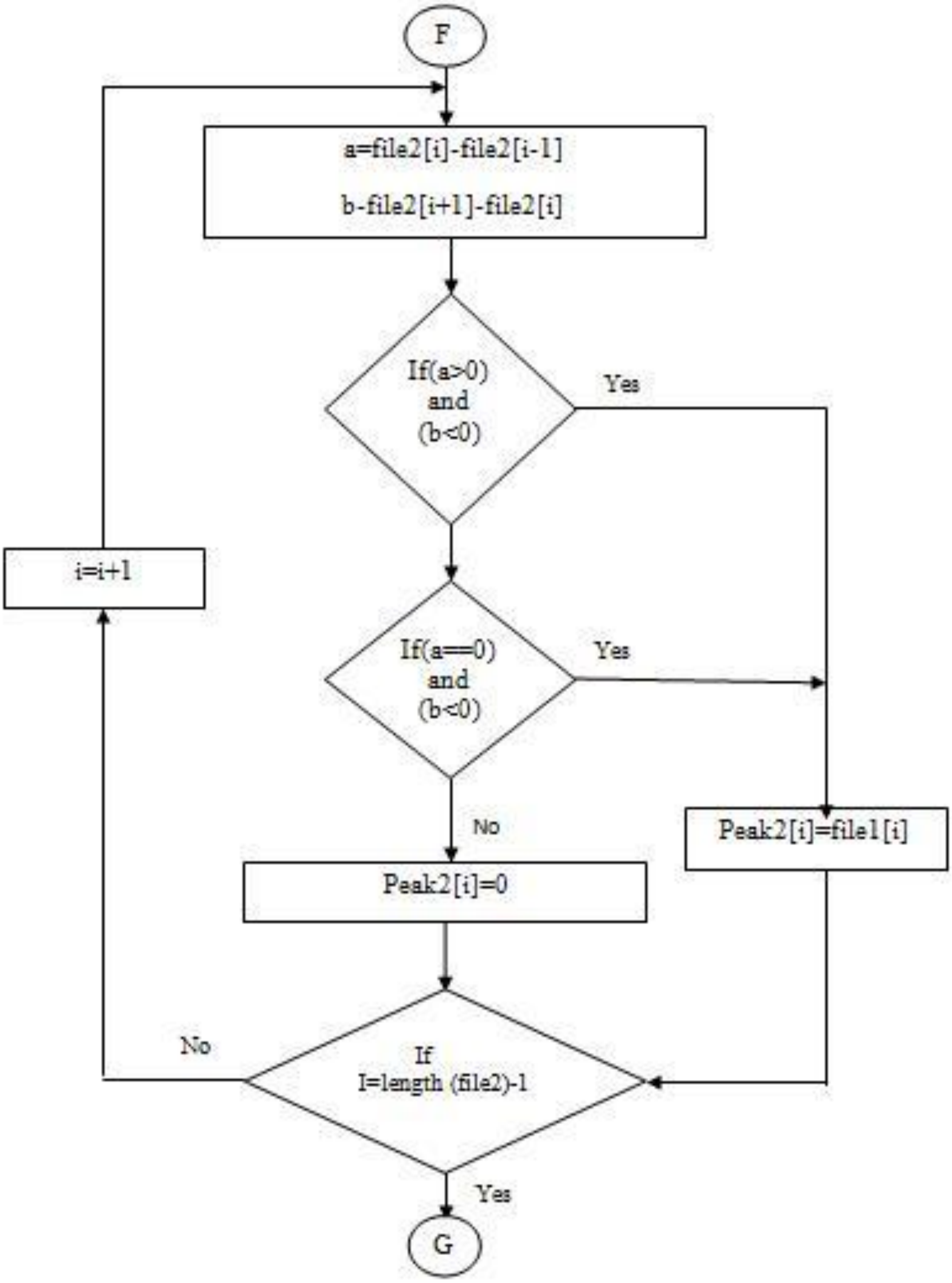
SAVING PEAKS AND RESPECTIVE TIME SAMPLE



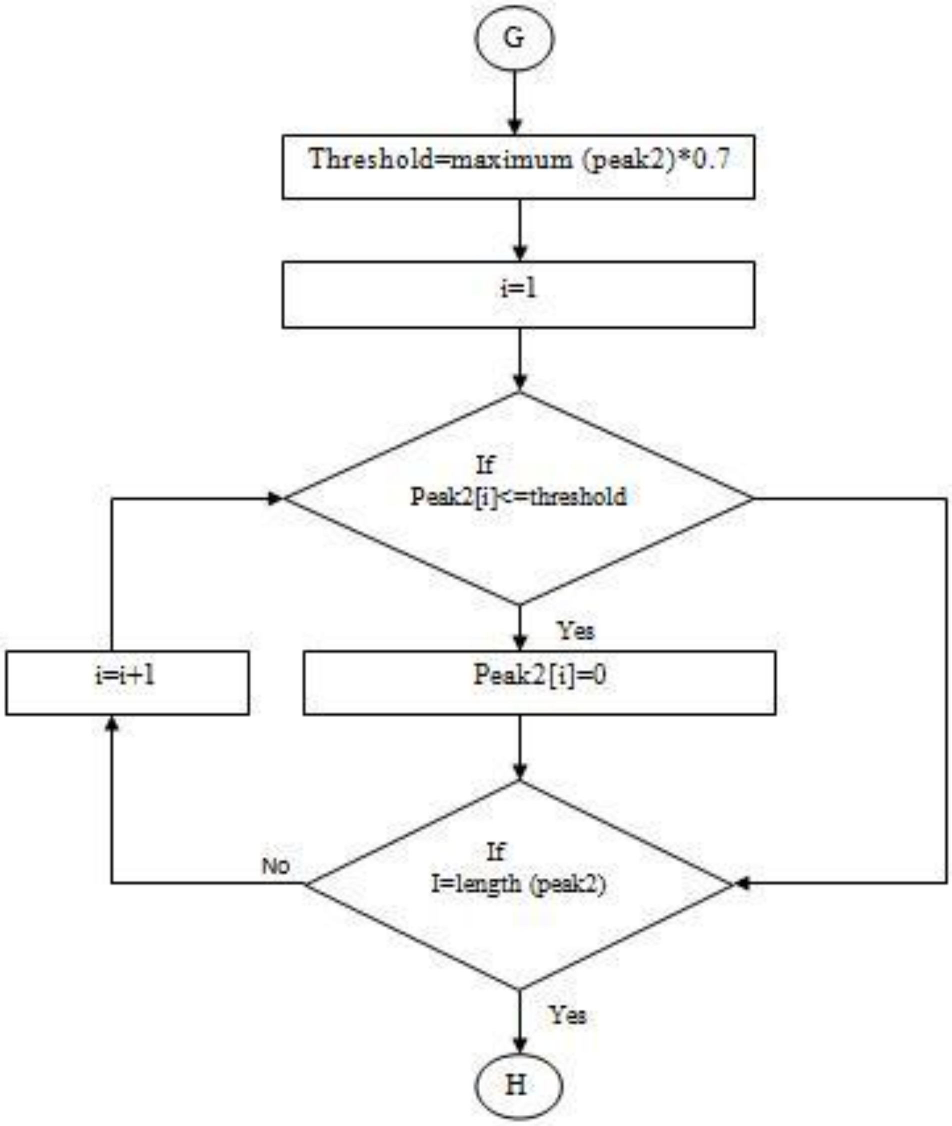
READING PPG SIGNALS FROM THE FINGER



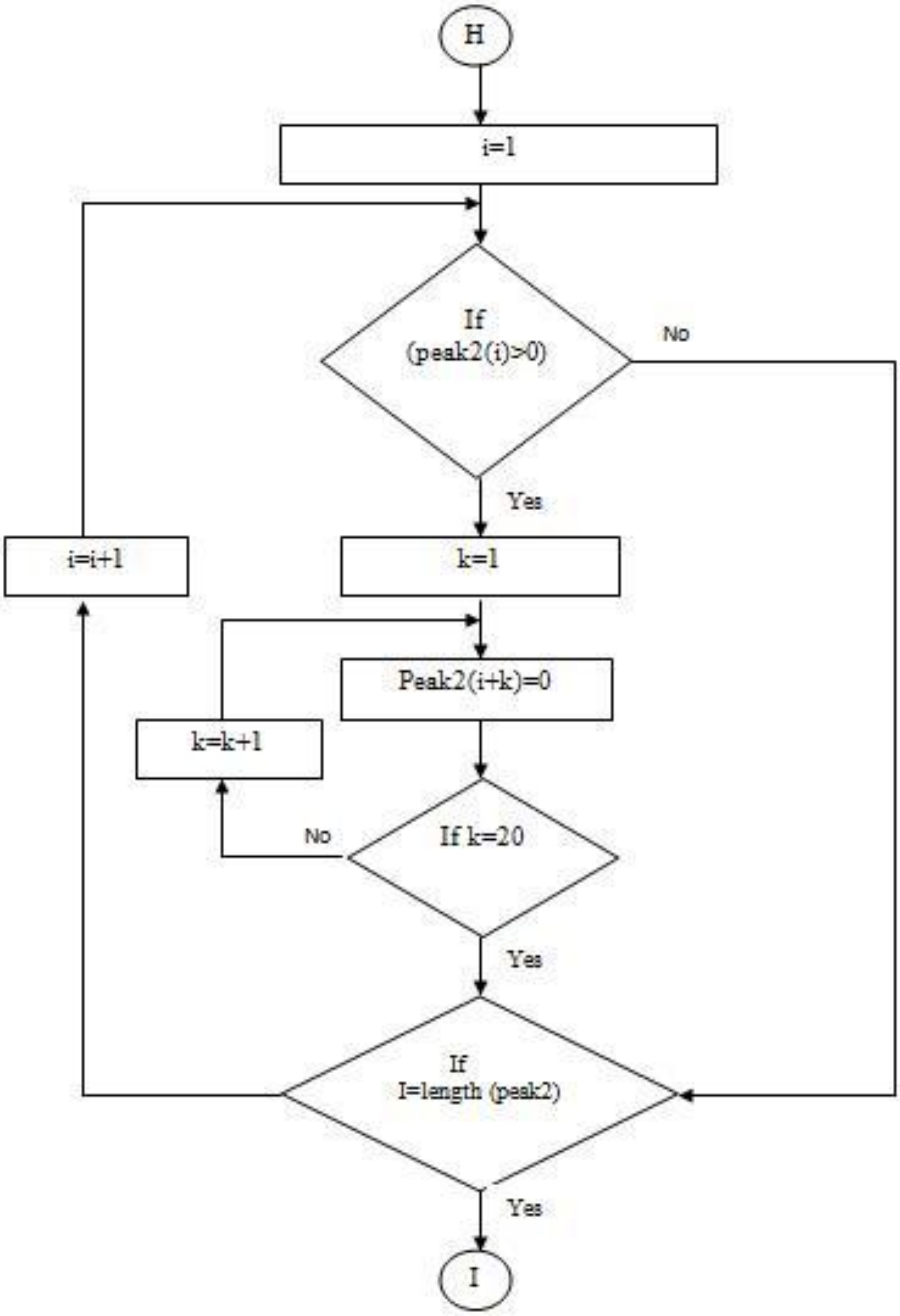
DETECTING FINGER PPG PEAKS



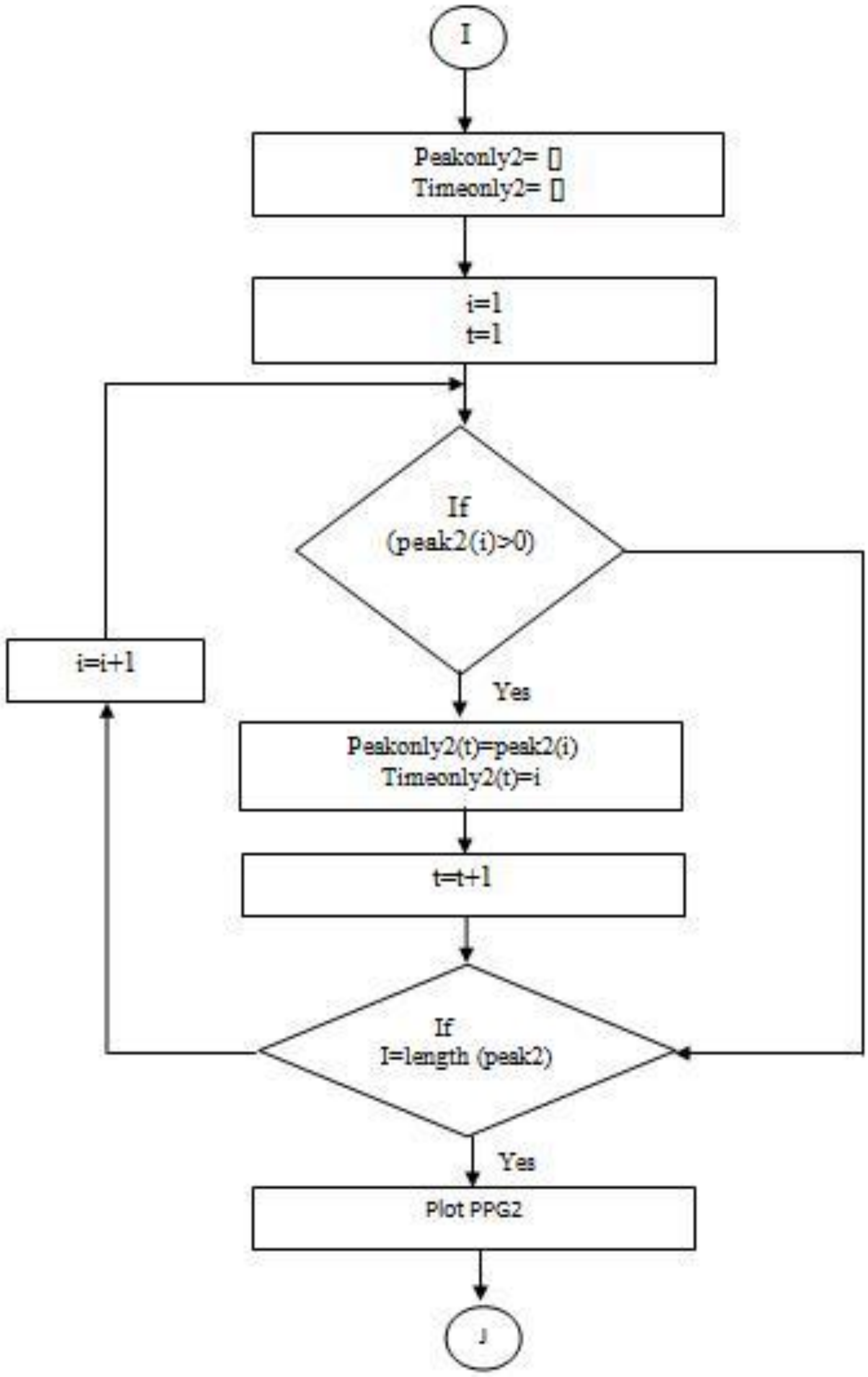
THRESHOLDING



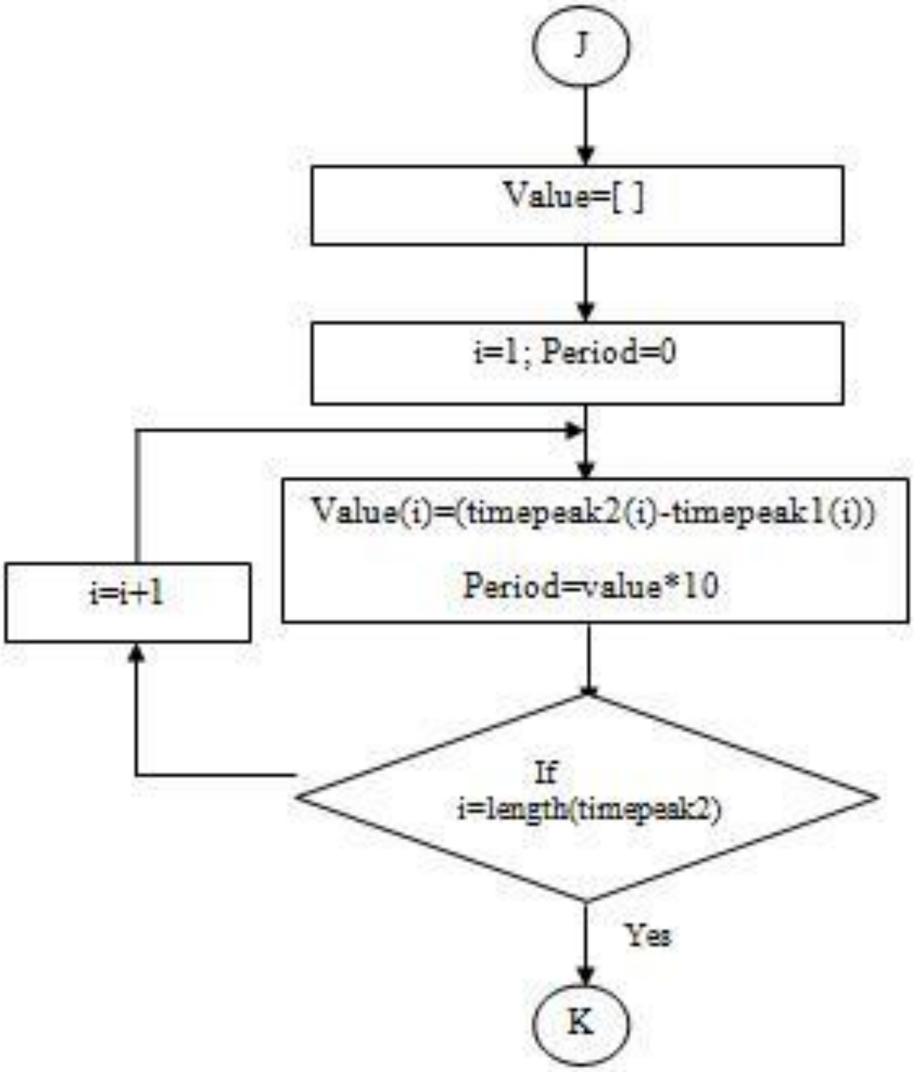
SUPPRESSING UNWANTED PEAKS



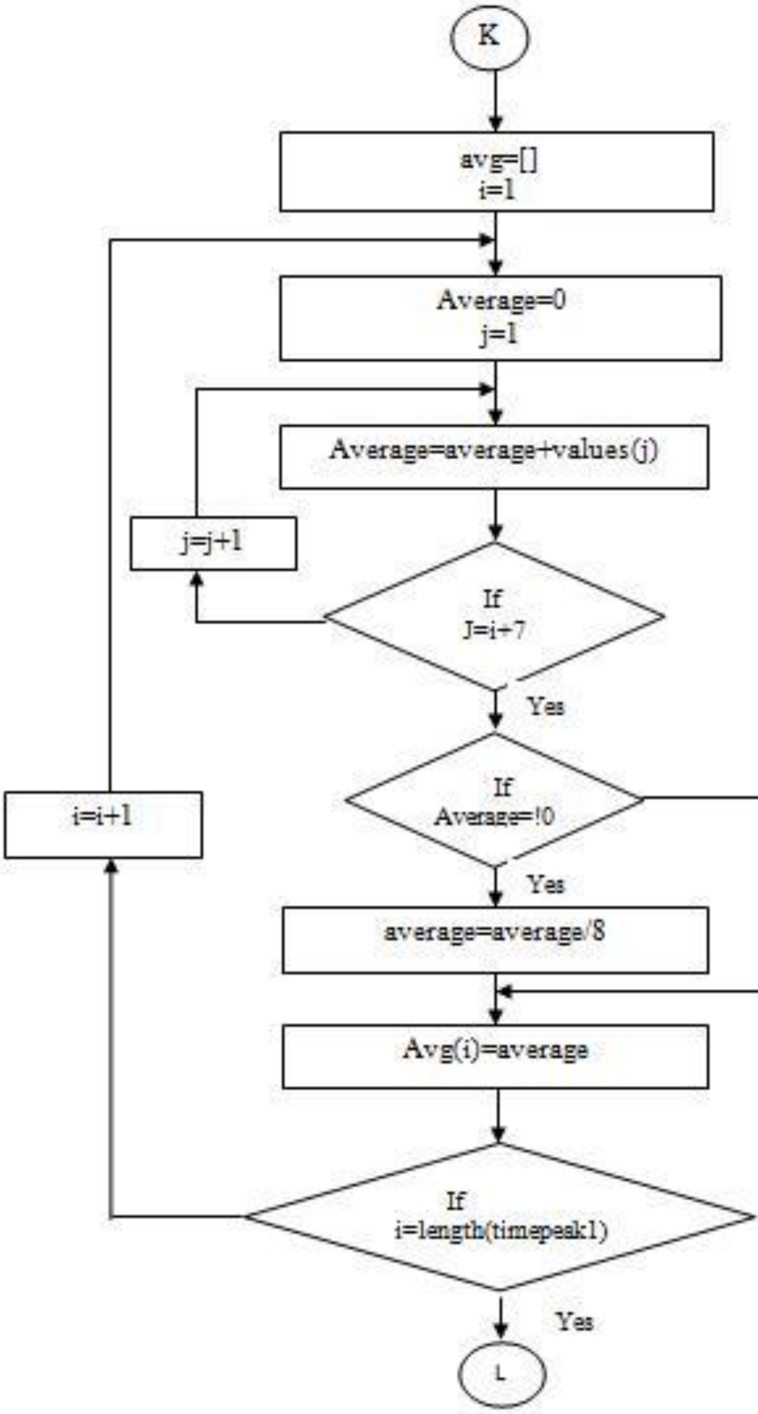
SAVING PEAKS AND RESPECTIVE TIME



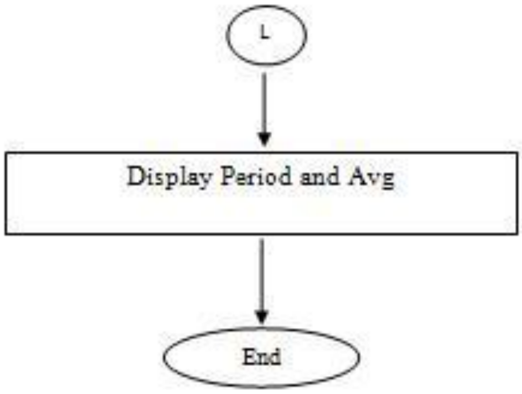
CALCULATING PULSE TRANSIT TIME



AVERAGING 8 SUCCESSIVE PTT VALUES



DISPLAYING RESULTS



3.9 MATLAB (Tool Used)

The above algorithm was implemented using the MATLAB. MATLAB stands for Matrix Laboratory. It is also used as a programming language for various applications. It is a high-level language and interactive environment that enables you to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and FORTRAN. This can use in a wide range of applications such as signal and image processing, communications, control design, test and measurement, financial modelling and analysis, and computational biology. Add-on toolboxes (collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas. The codes done with MATLAB can integrate with other languages and applications.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 HARDWARE DEVELOPMENT

The hardware of the reflectance PPG is developed on the breadboard and tested to collect the vital parameters. The reseults and discussions are as follows:

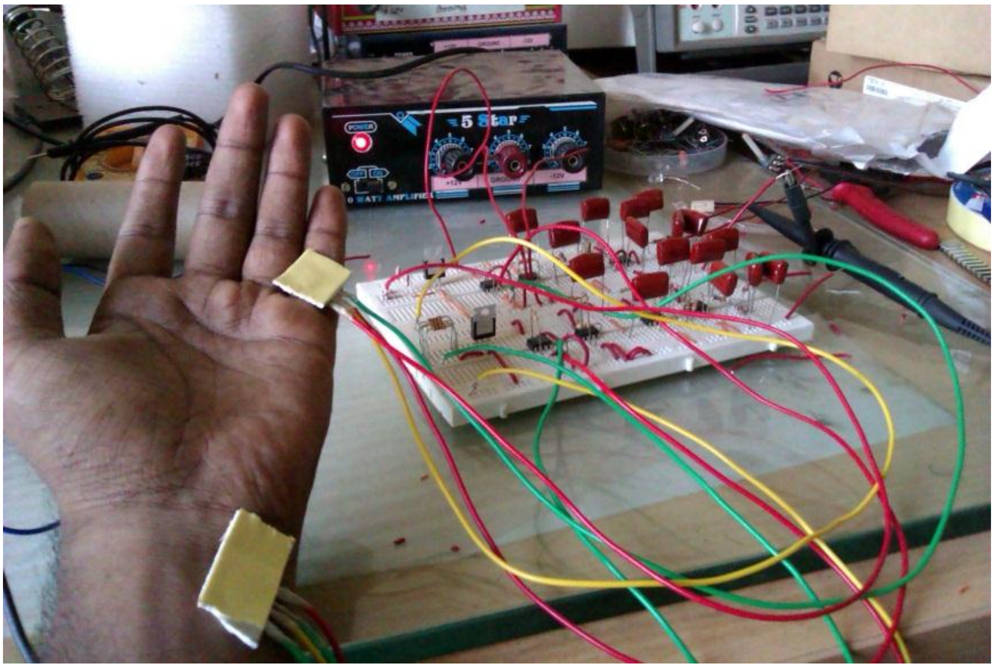


Fig 4.1: The reflectance wrist PPG setup

The above figure shows the reflectance PPG hardware that is instrumented on the breadboard.

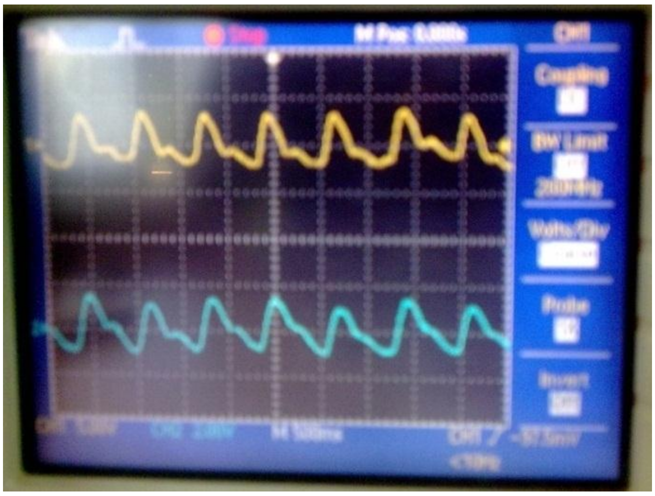


Fig 4.2: The reflectance wrist and finger PPG signals on CRO

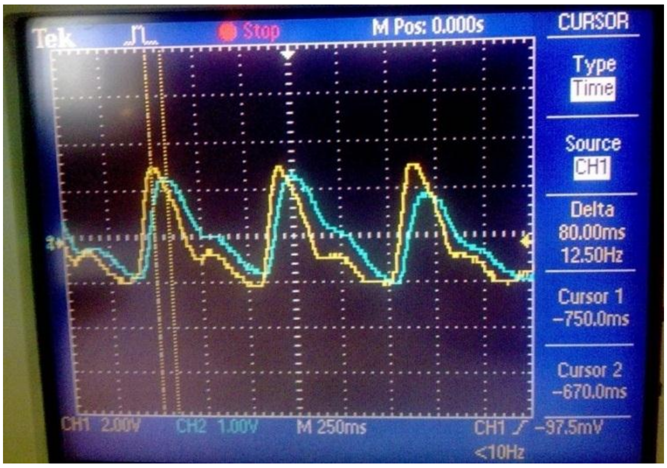


Fig 4.3: Overlapping of wrist and finger PPG waveforms

Fig 4.3 shows overlapped PPG signals acquired from Wrist and Finger on the CRO. Here the yellow waveform indicates the wrist PPG which is connected through channel 1 of the CRO and the blue waveform indicates the finger PPG which is connected through channel 2. Time difference between the peaks of these two signals is 80ms when measured manually with the cursor.

4.2 PTT CALCULATION USING MATLAB

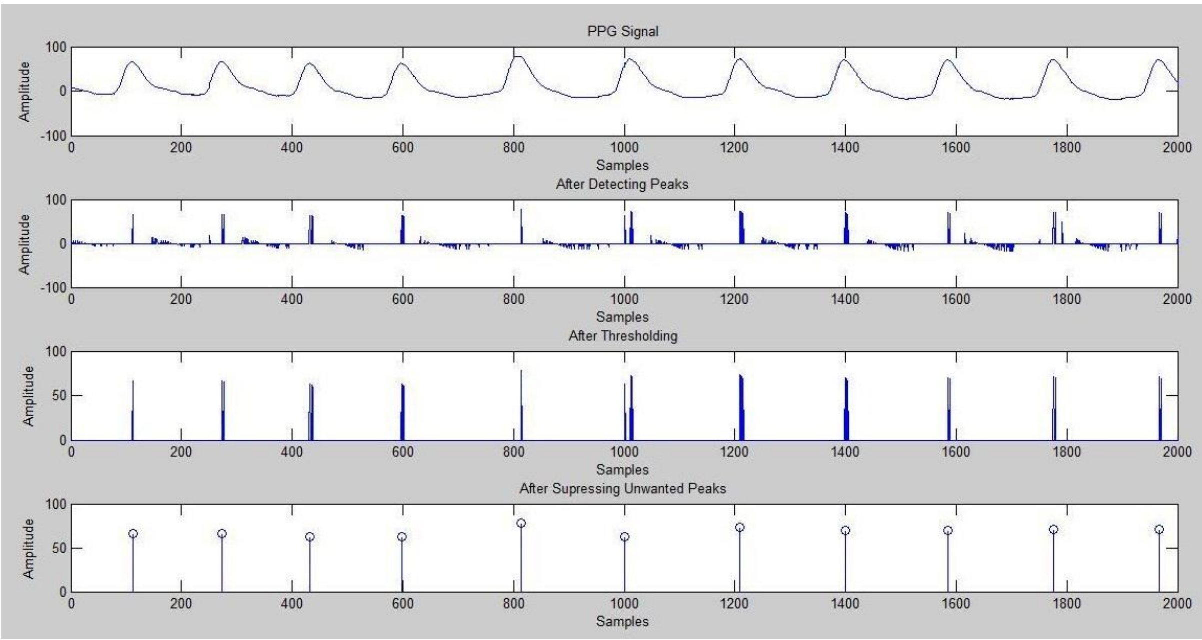


Fig 4.4: Snapshot from MATLAB with single PPG signal as input and its peaks detected

In the above snapshot, first graph shows the original acquired PPG signal, graph two represents the peak detection, graph three shows the threshold peak signals and graph four shows the final peaks.

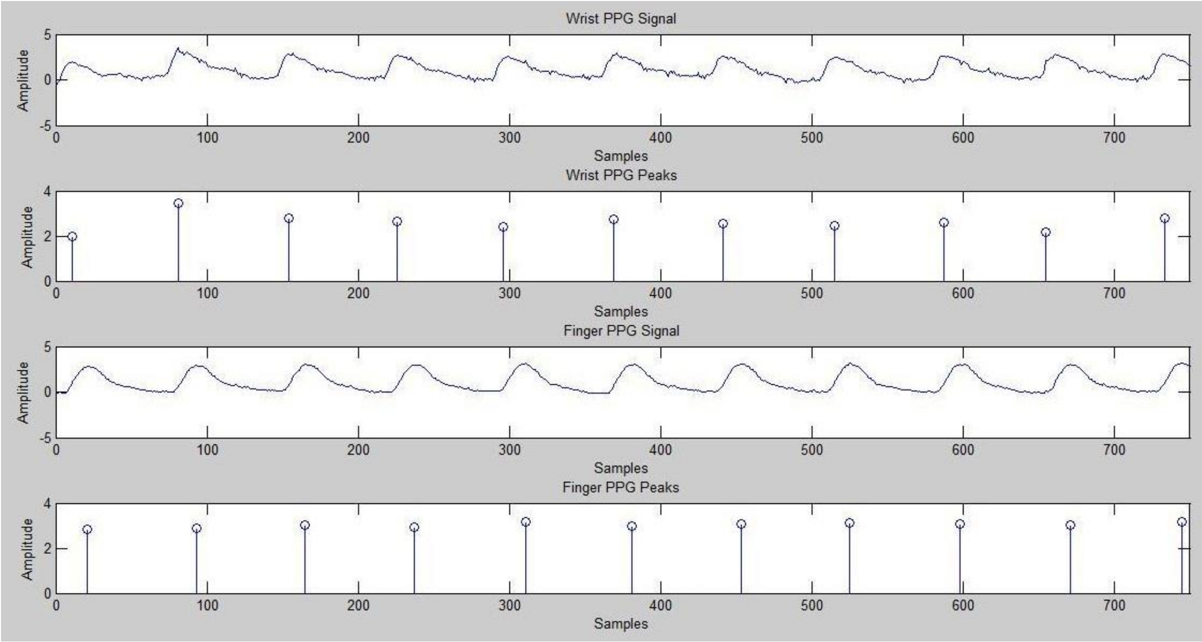


Fig 4.5: Snapshot shows the data plot of two PPG signals and the respective final PPG peaks detected by the implementation of the code developed.

The data for analysis was taken from 12 different subjects. These subjects are of age group between 21-31 years, and in the Height range of 158-183cms and weight range of 58-78Kgs. All the individuals are healthy in all aspects of physiological parameters. All the results were taken when the subjects were in rest condition.

The following table gives us the information regarding the data collected from various subjects for the calculation of PWV from the resultant PTT values obtained from the code developed. In the table below W stands for wrist and F stands for finger.

SUBJECT NUMBER	GENDER	AGE (yrs)	HEIGHT (cm)	WEIGHT (kgs)	PTT (W-F) (ms)	DISTANCE (W-F) cm	PWV (W-F) m/sec
1	Male	24	174	70	82	19	2.32
2	Male	31	183	78	87	21	2.41
3	Male	30	175	68	80	20	2.50
4	Female	21	161	60	99	19	1.92
5	Male	28	170	69	100	20	2.00
6	Female	23	158	58	96	18	1.88
7	Male	22	178	73	83	21	2.53
8	Male	25	172	70	94	21	2.23
9	Female	25	158	62	103	19	1.84
10	Female	21	162	64	110	18	1.64
11	Male	21	173	65	103	20	1.94
12	Male	23	169	75	98	19	1.93

PTT values obtained using peak detection algorithm

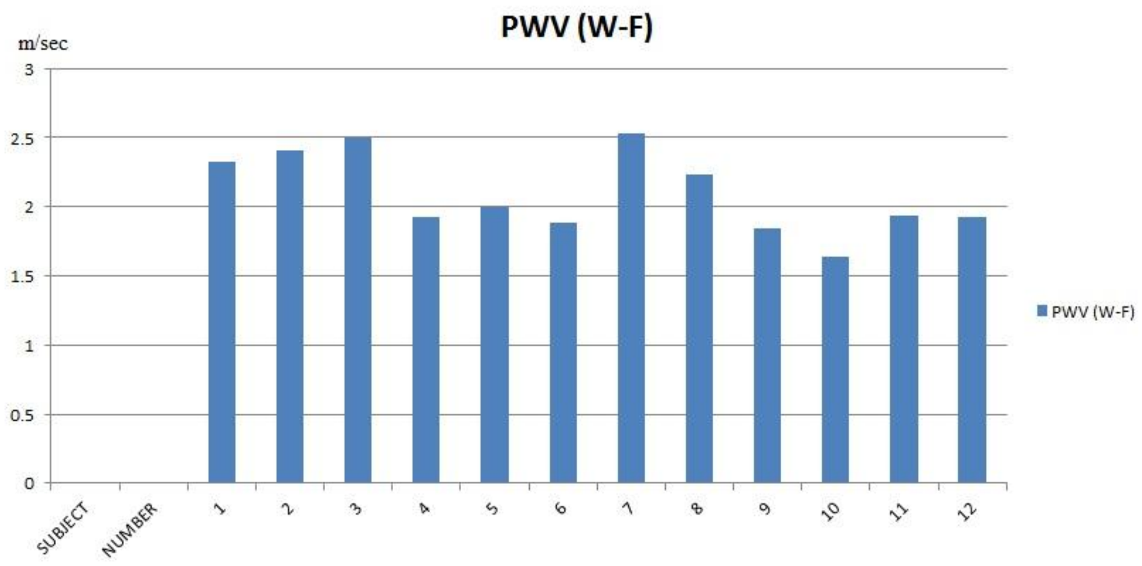


Fig 4.6: Plot showing PWV of various subjects

4.3 PROBLEMS FACED WHILE COLLECTING DATA

- Housing of the LED and Photo sensor.
- The pressure applied on the sensor varies the amplitude of the graph which is to be standardised.
- The long term usage of the sensor with pressure may lead to necrosis of the tissue.
- Motion artefacts result in distortions of the waveforms.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

The results clearly indicate that Pulse Transit Time (PTT) can be calculated using two Photo Plethysmograph circuits, a wrist PPG and a finger PPG circuit which can successfully replace the utilisation of Electrocardiograph (ECG) and this also avoids the complexity of measuring the distance from heart to finger.

The hardware unit was successfully instrumented and software algorithm was implemented to calculate Pulse Transit Time.

5.2 FUTURE SCOPE

The sensor must be thin and unobtrusive so that discomfort faced by the subject is minimised. The sensor may make the subject face some difficulties in wearing the sensor for long time duration which has to be addressed. The complete hardware unit should be wireless and incorporated by MEMS (Micro Electro Mechanical System) technology which reduces its size and can be made wearable.

5.2.1 HEIGHT MEASUREMENT SENSOR

The relative height of the device measurement site can be determined using a pair of 3-axis accelerometer, one located in the finger sensor housing and a second located at the wrist. To implement Adaptive Hydrostatic Pressure algorithm

5.2.2 REMOVAL OF MOTION ARTIFACTS

The software has to be incorporated with motion reduction algorithms (e.g. Adaptive Noise cancellation, singular value decomposition) such that the motion artefacts are removed prior to PTT calculation. The obtained PTT will then be implemented to calculate blood pressure by using regression analysis.

5.2.3 DESIGN OF POWER SUPPLY

A constant 5V DC power supply can be designed so that the device can be made fully portable in its use. This also can make the device economical.

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